OGLE-TR-56

Guillermo Torres[*], Maciej Konacki[†], Dimitar D. Sasselov[*] and Saurabh Jha[**]

[*]*Harvard-Smithsonian Center for Astrophysics*
[†]*Caltech, Department of Geological and Planetary Sciences*
[**]*University of California–Berkeley, Department of Astronomy*

Abstract. In early 2003 our team announced the discovery of the second extrasolar transiting planet, around the faint star OGLE-TR-56 ($V = 16.6$), based on the detection of small changes in the radial velocity of the primary. The star was originally identified as a candidate by the OGLE team from the shallow and periodic dips in its brightness. We present here new precise radial velocity measurements that confirm the variation measured earlier, supporting the conclusion that the companion is indeed a planet. Additional photometric observations are also available, which combined with the spectroscopy yield improved parameters (mass and radius) for the planet.

INTRODUCTION

One of the most successful searches for transiting extrasolar planets to date has been the OGLE survey, which has uncovered a total of 137 candidate transiting planets in several fields toward the bulge of the Galaxy and in the constellation of Carina [1, 2, 3, 4]. All of these stars show small dips in brightness at the level of a few percent, suggesting the presence of a low-mass companion in orbit. The stars are typically much fainter than the usual targets of transit surveys, ranging in brightness from about $V = 14$ to $V = 19$. The fields toward the Galactic center are also quite crowded.

In 2002 we began a systematic spectroscopic follow-up campaign in the bulge sample to weed out “false positives". Examples of false positives include a stellar (as opposed to a substellar) companion orbiting a large star (B-A main sequence star, or a giant), grazing eclipses in a stellar binary, or contamination by the light of a fainter eclipsing binary along the same line of sight (referred to as a “blend"), so that the otherwise deep eclipses of that binary are diluted by the other star and look very shallow (transit-like). As a result of that campaign, we were able to rule out up to 98% of the original candidates as false positives, and we then focussed on the remaining handful of good candidates for higher-precision work.

In early 2003 our team announced the discovery of the planet around the star OGLE-TR-56 ($V = 16.6$), with a period of only 1.21 days [5]. So far this is the only known transiting extrasolar planet aside from the well-known case of HD 209458b [6, 7].

We report here additional observations that confirm the original radial velocity variation detected by [5], and improve the estimate of the mass of the planet. We also report an updated light curve solution based on new OGLE photometry, yielding an improved planetary radius.

CP713, *The Search for Other Worlds: Fourteenth Astrophysics Conference,*
edited by S. S. Holt and D. Demings

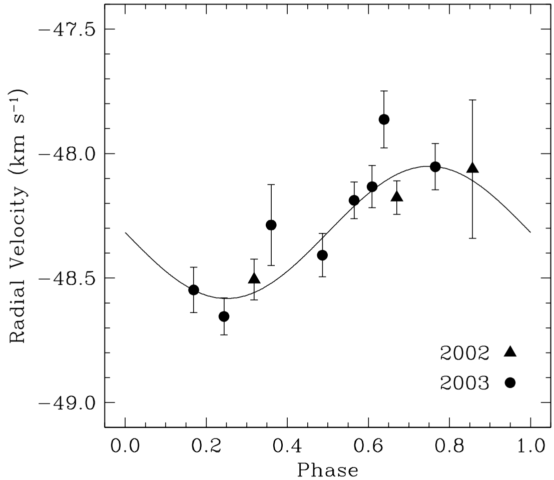

FIGURE 1. Radial velocity observations and velocity curve for OGLE-TR-56, as a function of orbital phase (fixed from the photometry).

SPECTROSCOPIC OBSERVATIONS AND ORBITAL SOLUTION

High-resolution spectra were obtained with the Keck I telescope using the HIRES instrument (High-Resolution Echelle Spectrometer) on two runs during August 1–3 and August 11–12 of 2003. This is the same instrumentation used by [5] for the original observations that led to the planet discovery. The resolving power achieved is $\lambda/\Delta\lambda \approx 65,000$. The wavelength reference was established using exposures of a Thorium-Argon lamp before and after each stellar exposure.

Radial velocities were obtained by cross-correlation against a synthetic template for OGLE-TR-56 with parameters matching those of the star. The uncertainties in the radial velocities are limited by systematics at the level of about 100 m s^{-1}, as described in more detail by [8]. Internal errors are smaller, ranging from 70 to 90 m s^{-1} in most cases.

Because the object transits the parent star every 1.21 days, the ephemeris is well known from the light curve analysis (see below). We have adopted this ephemeris for the spectroscopic solution, and so the only parameters that need to be adjusted are a radial velocity offset and the velocity semi-amplitude (K), since the orbit is assumed to be circular.

Our radial velocity curve is shown in Figure 1, where the circles represent the 8 new measurements (August 2003) and the triangles are based on the original 3 spectra by [5], re-reduced for uniformity.

The new measurements confirm the variation detected originally, although with a larger amplitude than the first estimate, which was based on only 3 observations (with two free parameters). The significance of the determination is now much greater, as

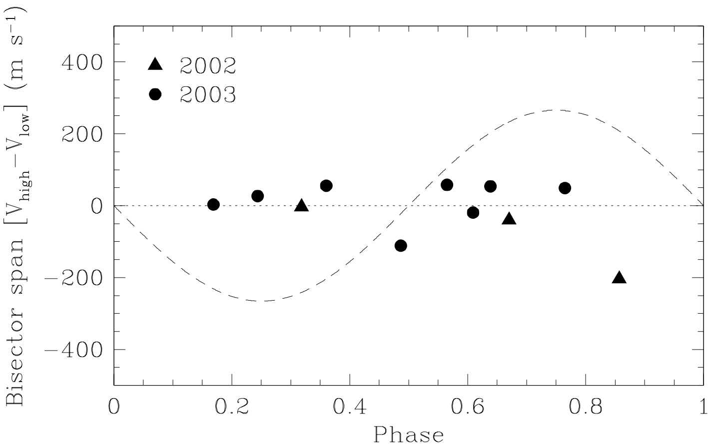

FIGURE 2. Bisector span used as a proxy for line asymmetry for each of our spectra of OGLE-TR-56, as a function of orbital phase. Over-plotted for reference is the velocity curve from Fig. 1, which shows that there is no correlation of the asymmetries with phase.

can be seen visually in the figure, and the errors are better characterized because of the increased number of observations. The measured K amplitude is 265 ± 38 m s^{-1}, and the RMS residual from the fit is 114 m s^{-1}. The minimum mass for the planet is $M_p \sin i = 1.33 \pm 0.21 \times 10^{-3}$ M$_\odot \times (M_* + M_p)^{2/3}$, where M_* is the mass of the parent star and i is the inclination angle of the orbit. The absolute mass of the planet is derived below.

TESTING FOR BLENDS: THE SPECTRAL LINE BISECTORS

Spurious radial velocity measurements can result if the spectral lines of the main star are blended with those of another fainter object, which can introduce slight asymmetries in the line profiles. Changes in the asymmetry correlating with orbital phase are a sign that the velocity variations are not real, and thus that there is no planet.

We have tested this for OGLE-TR-56 by computing the spectral line bisectors [e.g., 9] for each of our spectra directly from our cross-correlation functions, which are representative of the average spectral line profile. The difference in velocity between the bisectors at two different levels in the correlation function ('high' and 'low') is defined as the "bisector span", and is used as a measure of the asymmetry of the mean spectral line.

Figure 2 shows the bisector span as a function of orbital phase. For reference we display also the orbital solution from Figure 1. There is no significant correlation with phase, either positive or negative. This means that the velocity variations measured above are real, and thus confirms that we have a planet.

TABLE 1. Orbital and physical parameters for OGLE-TR-56b.

Parameter	Value
Orbital period (days)	1.2119189 ± 0.0000059
Transit epoch (HJD−2,400,000)	52075.1046 ± 0.0017
Center-of-mass velocity (km s^{-1})	-48.317 ± 0.045
Eccentricity (fixed)	0
Velocity semi-amplitude (m s^{-1})	265 ± 38
Inclination angle (deg)	81.0 ± 2.2
Stellar mass ($M_{\odot}$) (adopted)	1.04 ± 0.05
Stellar radius ($R_{\odot}$) (adopted)	1.10 ± 0.10
Limb darkening coefficient (*I* band)	0.56 ± 0.06
Planet mass (M_{Jup})	$\mathbf{1.45 \pm 0.23}$
Planet radius (R_{Jup})	$\mathbf{1.23 \pm 0.16}$
Planet density (g cm^{-3})	$\mathbf{1.0 \pm 0.3}$
Semi-major axis (AU)	0.0225 ± 0.0004

RESULTS AND CONCLUSIONS

Additional photometric transits have been detected by the OGLE team in 2003 (for a total of 13), and refinements in the analysis have removed small systematic errors in the original photometry. We have carried out a new light curve solution resulting in an improvement in the photometric parameters.

The results for OGLE-TR-56 are given in Table 1. The planet is twice as massive as HD 209458b, but has approximately the same size and orbits at only half the distance to its parent star. This makes it particularly interesting from the theoretical point of view.

Several other good transit candidates from the lists released by the OGLE team are currently being followed up spectroscopically with Keck. With the measurement and analysis techniques we have developed, we expect to be able to discriminate with a high degree of confidence between true planets and false positives.

REFERENCES

1. Udalski, A., Paczyński, B., Żebruń, K., Szymański, M., Kubiak, M., Soszyński, I., Szewczyk, O., Wyrzykowski, Ł., & Pietrzyński, G. 2002a, Acta Astron., 52, 1
2. Udalski, A., Żebruń, K., Szymański, M., Kubiak, M., Soszyński, I., Szewczyk, O., Wyrzykowski, Ł., & Pietrzyński, G. 2002b, Acta Astron., 52, 115
3. Udalski, A., Szewczyk, O., Żebruń, K., Pietrzyński, G., Szymański, M., Kubiak, M., Soszyński, I., & Wyrzykowski, Ł. 2002c, Acta Astron., 52, 317
4. Udalski, A., Pietrzyński, G., Szymański, M., Kubiak, M., Żebruń, K., Soszyński, I., Szewczyk, O., & Wyrzykowski, Ł. 2003, Acta Astron., 53, 133
5. Konacki, M., Torres, G., Jha, S., & Sasselov, D. D. 2003a, Nature, 421, 507
6. Henry, G. W., Marcy, G. W., Butler, R. P., & Vogt, S. S. 2000, ApJ, 529, L4
7. Charbonneau, D., Brown, T. M., Latham, D. W., & Mayor, M. 2000, ApJ, 529, L45
8. Konacki, M., Torres, G., Sasselov, D. D., & Jha, S. 2003b, ApJ, 597,1076
9. Gray, D. F. 1992, The Observation and Analysis of Stellar Photospheres, 2nd Ed. (Cambridge: Cambridge Univ. Press), 417